SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V13I7P113

Volume 13 Issue 7, 212-224, July 2026

Original Article

Regulating Urban Form in the Digital Age: Transitioning from Prescriptive Norms to Form-Based Codes in Astana, Kazakhstan

Muldagaliyeva Ainur[1], Feoktistova Yelena[2], Gurskaya Oxana[3], Kriulko Nina[4], Barakbayev Arslan[5]

[1,5]*Department of Architecture, S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan.*
[2,3,4]*Department of Architecture, D. Serikbaev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan.*

[1]*Corresponding Author : muldagaliyeva.ainur@gmail.com*

Received: 06 March 2026 Revised: 05 May 2026 Accepted: 02 July 2026 Published: 29 July 2026

Abstract *- This study addresses the structural incompatibility between inherited post-Soviet urban regulations and the requirements of contemporary digital planning in transition economies. Using Kazakhstan as a case study, the research aims to develop a framework for adapting prescriptive regulatory systems to automated compliance-checking environments. A mixed-methods approach is employed, combining comparative content analysis of 150 regulatory provisions, morphological simulation of development scenarios in Astana, and an algorithmization experiment. The study reveals a critical «Interpretation Gap»: approximately 70% of legacy norms rely on subjective language that resists machine interpretation, whereas in Vienna and Buffalo, on average, 87.4% of provisions are machine-readable. Morphological modelling further indicates that current norms produce a fragmented, vehicle-oriented urban structure, whereas form-oriented regulation considerably increases street-level vitality (Active Street Frontage Ratio rising from 15% to 75%) without sacrificing density (FAR ≈ 2.5–2.8). On the basis of these findings, a dual-track reform strategy is proposed: prescriptive logic is retained for safety-critical norms (translated into machine-readable formats), while obsolete urban-planning norms are replaced with adaptable Form-Based Codes. The hybrid model offers a scalable pathway for bridging the divide between technocratic legacy structures and the demands of sustainable, digitally enabled urban planning in post-Soviet countries.*

Keywords *- Automated Code Compliance Checking, Building Information Modelling, Form-Based Codes, Kazakhstan, Post-Soviet urban planning.*

1. Introduction

Globally, the management of urban and regional planning is experiencing significant transformation. There is a trend of gradual shift from the strict functional zoning to the more flexible regulatory systems of urban planning [1, 2]. On the basis of this transition, two interconnected instruments were developed: Form-Based Codes (FBCs) – structural codes that regulate the physical structure of the urban morphology, and Performance-Based Codes (PBCs) – codes that based on the efficiency indicators that set qualitative and ecological parameters [1, 2].

Together with this conceptual transformation, a technological transformation is also taking place. Leading cities integrate instruments of the automized machine verification of compliance, Automated Code Compliance Checking (ACCC), and Building Information Modelling (BIM), a tool that allows optimizing the permit issuing process [3, 4]. However, in countries with transitional economies, structural hurdles remain due to the deep-rooted nature of the inherited regulatory system and limited maturity of the basic infrastructural data [5].

In post-Soviet countries, including Kazakhstan, structural problems of urban planning are closely linked with the institutional history of the country. The planning system in Kazakhstan is operating on the basis of the inherited soviet construction norms and rules (SNiP). These norms firstly were introduced in 1958 in order to secure the industrialization and state programs of the mass housing development. Despite significant revision, current Kazakhstani norms conceptually and systematically remain connected with the soviet prototypes. These norms were not developed for the people-centered urban morphology, but mostly developed for the standardization of the construction and development in consistency with the industrial production goals [6]. This legacy remains evident in the planning principles of the modern Astana, the fast-growing city which districts are still

designed under the influence of the mid-20th century urban planning principles.

This historical context creates a fundamental hurdle for the digital transformation. Norms of the Soviet period are predominantly of a prescriptive nature. Soviet norms focus on the fixed empirical standards that secure the safety, while lacking attention to the qualitative characteristics, such as spatial experience and place identity. Legal language is often vague and admitting various interpretations that creates significant obstacles for automation of the processes. Terms such as «in general» or «is permitted when justified» cannot be directly transformed to the machine-readable logic. Researches of the automated verification in Vienna [7], Estonia [8], and Brazil [9] confirms that the semantic ambiguity and inconsistency of the traditional norms establish a serious obstacle for the introduction of the ACCC systems [3, 10].

1.1. Research Gap

This situation reveals an obvious research gap. Despite the fact that significant attention in the global scientific agenda is paid to the improvement of form-based codes and performance-based codes within the already flexible western regulatory systems, very few methodological approaches are developed for the transition of the prescriptive norms of the Soviet period into formats that are compatible with the automated and result-oriented planning instruments. In the existing literature, three specific shortcomings can be identified. Firstly, comparative researches, for example [3, 10], as a rule, compares national norms between each other, but do not conduct a systemic analysis of the post-Soviet legal texts.

Secondly, researches on the introduction of the ACCC usually proceeds from the assumption that the source regulatory text is already syntactically clear and quantitatively expressed; however, this assumption does not work when applied to the provisions in the SNiP style. Thirdly, existing researches of the countries with transitional economies are focused mainly on the institutional or managerial side of the digitalization [8], without examining how the regulatory text itself is limiting the automation. To the best of the authors' knowledge, currently there are no published researches that systemically map the linguistic and morphological obstacles for the algorithmization of the inherited norms, such as SNiP RK, and at the same time propose a framework model that reforms both the content of these norms, from the prescriptive to the result-oriented approach, and their structure, from the natural language to the machine-readable logic. The present article is aimed at filling this insufficiently studied direction.

1.2. Aim, Objectives and Research Questions

The general aim of this research is the development of a methodological framework for the reconfiguration of the inherited post-Soviet regulatory systems into a hybrid, digitally compatible model that integrates both elements oriented on the efficiency indicators and the form-based elements, on the example of the city of Astana, Kazakhstan. For the achievement of this aim, four specific objectives are set:

- To compare structural and linguistic features of the post-Soviet regulatory texts, SNiP RK, and the western regulatory documents, Vienna OIB-Guidelines and Buffalo Green Code, with the use of a specially developed classification matrix;
- To quantitatively assess morphological consequences of the indicated regulatory regimes through the 3D-simulation of a real plot in Astana;
- To verify the algorithmic translatability of the selected SNiP provisions with the aim of revealing concrete linguistic and logical obstacles for the automation;
- To propose a two-loop reform strategy that connects the empirical results with the realistic transition trajectory for Kazakhstan and similar post-Soviet contexts.

The research is guided by three research questions:

RQ1: To what extent are the provisions of SNiP RK machine-readable in comparison with the norms of Vienna and Buffalo?

RQ2: In what way do the prescriptive norms, SNiP, and the form-based norms, FBC, shape the urban morphology when applied to the same plot under the same density?

RQ3: Which categories of the SNiP provisions can be translated into the algorithmic logic, and which form an insurmountable «Interpretation Gap»?

1.3. Novelty and Contribution

The present research differs from the previous works by three main contributions. Firstly, it introduces the Digital Readiness Matrix, an original classification instrument for the assessment of the algorithmic compatibility of the urban planning provisions. This instrument extends the rule classification scheme, proposed by Solihin and Eastman [10], through the addition of the linguistic markers that are characteristic for the inherited prescriptive norms. Secondly, the research presents the first quantitative comparison of the post-Soviet and western regulatory texts by the parameter of digital readiness; existing comparisons, for example [3, 7, 9], consider only the western or East Asian norms. Thirdly, by combining the text analysis, the morphological simulation and the algorithmization testing on the same plot, the research connects three directions that mainly developed separately from each other: the regulatory linguistics, the urban morphology and the introduction of the ACCC. The empirical conclusion that approximately 70% of the SNiP provisions are not directly machine-readable, in contrast with the average indicator of 87.4% for the samples of Vienna and Buffalo, was not previously presented in the scientific literature and forms a concrete reference point for the subsequent researches in the post-socialist contexts.

2. Literature Review

Modern scientific discussions in the sphere of urban planning regulation are predominantly focused on the shortcomings of the traditional Euclidean zoning, which is currently more and more considered as insufficient for the promotion of sustainable development and for the provision of the high quality of the urban environment. In the literature, two main global tendencies are highlighted: the transition of the regulatory logic from the prescriptive approach to the form-based and result-oriented models, and also the parallel movement towards technological integration, especially the application of the Automated Code Compliance Checking (ACCC) within the environment of the Building Information Modelling (BIM) [3]. In contrast with this, in the post-socialist countries, such as Kazakhstan, the regulatory context is developing along a different trajectory and creates a significant barrier for the introduction of the indicated global achievements, as it is pointed out by Stanilov [6] and Alexander [16]. The urban planning systems of the countries of Central and Eastern Europe preserved the technocratic and prescriptive logic for a long time after the collapse of the Soviet Union. This legacy is embodied in the construction norms and rules (SNiP), which appeared in the Soviet Union and in Kazakhstan in the structural relations, mostly remain unchanged. In contrast with the modern flexible codes, the Soviet SNiP were developed for the standardized industrial mass construction, and their principles, by their nature, are prescriptive and do not correspond with the digitalization or with the modern efficiency indicators. As a result, while urban systems in other countries are transitioning to the digitalized, predictive and result-oriented planning, the planning practice in Kazakhstan continues to reflect the norms of the Soviet period. This discrepancy makes it difficult to adapt modern technologies, such as ACCC.

2.1. Evolving Regulatory Logic: From Function to Form and Performance

Functional zoning is criticized for the fact that it contributes to the formation of the mono-functional and spatially disconnected urban territories [2]. As a response to this, more and more cities are introducing the Form-Based Codes (FBCs), form-shaping codes that focus attention on the spatial and volumetric-planning qualities of the urban environment. Parolek et al. [1] show that such codes regulate the urban structure more effectively than zoning based on the types of land use, since the priority is given to the physical form of the built environment. The realization of the Buffalo Green Code in the city of Buffalo, New York State, demonstrates in what way the form-based codes can strengthen the local character of the environment and increase the feeling of the place identity in the urban districts through the regulation of the placement of the buildings and of the character of the street front, and not only of the functional use of the land [11]. This reflects a wider turn from the regulation of the function towards the formation of the urban form and the spatial experience.

At the same time, the form-based codes have their own limitations. Despite the fact that they focus attention on the physical form and the urban character, they often insufficiently take into account the indicators of ecological efficiency. Shach-Pinsly and Capeluto [12] provide empirical evidence of the continuing transition, showing how the regulatory frameworks, originally based on the form-shaping approach, more and more include result-oriented elements, such as access to sunlight and energy efficiency. Chin [13] additionally argues that the translation of such hybrid norms into the predictive and machine-readable formats is a necessary condition for the development of the next generation of urban planning regulation. For the direct overcoming of these limitations, researchers have proposed the Performance-Based Codes (PBCs), codes that are based on the efficiency indicators. They define measurable results, for example, the threshold values of the natural illumination or the target indicators of the energy efficiency, while at the same time preserving the design flexibility in the ways of the achievement of these results [4]. Such an approach to a significant degree relies on the integration of the three-dimensional analytical instruments into the process of the planning and design. Although FBCs and PBCs are usually considered as independent planning instruments, modern researches show that they are more and more often combined. Such hybrid models include requirements for the physical form, for example, the building lines, the density of the development of the plot, the rules of the formation of the street front, together with the indicators of the efficiency, for example, the threshold values of the insolation and the levels of the natural illumination of the internal premises. In practice, this allows the cities to simultaneously shape the external appearance and the perception of the place, and also to ensure the achievement of the measurable results. The dual approach makes the planning system adaptive and predictable, and not reactive.

2.2. Digitalization and Automation in Regulatory Practice

Together with this conceptual shift, a structural transformation is also taking place, connected with the digitalization of the regulatory processes. Cities are more and more often embedding the planning requirements into the BIM environments for the automation of the procedures of the issuance of permits [14]. Vienna represents an illustrative example. Urban et al. [7] describe how the city is developing a system that is compatible with the OpenBIM, which uses the IFC models for the verification of compliance with the urban planning norms. The success of such a system depends on the clearly defined information requirements, which the authors designate as «Level of Information Need». Brazil has gone along an analogous path: Villaschi et al. [9] developed a system with the use of Dynamo, a visual programming environment, for the automation of the checks of the accessibility and the zoning, showing that the algorithmic translation of the rules can accelerate the design processes. Sweden, in its turn, is developing national standards that

connect the 3D models with the legal and cadastral data, with the aim of the creation of a seamless digital regulatory process [15]. The recent systematic review by Sihao Li et al. [20] reveals a common bottleneck across all of these initiatives: independently of the level of the maturity of the basic BIM platform, the automation gives a failure when the regulatory text itself remains ambiguous. From this, it follows that the linguistic reform of the regulatory documents is no less important than the introduction of the new digital instruments.

2.3. Barriers between Process and Technology

Despite the indicated innovations, the transition to the digital instruments is often restrained by the inherited institutional inertia. Researches of the introduction of the BIM in Estonia [8] shows that the main problems have an organizational character: the unclear legal framework, the resistance to the changes, and the outdated procedures. The inherited regulatory norms, composed in natural language for manual interpretation, represent an especially complicated problem. Their indefinite and frequently subjective formulations make it difficult to translate them into precise algorithms based on the rules, without a deep semantic restructuring.

Solihin and Eastman [10] confirm that the classification of the rules and the elimination of the semantic ambiguity are necessary preliminary conditions for any ACCC system. The more recent work of Peng and Liu [21] proposes the use of the knowledge graphs for the formalization of the semantics of the rules, whereas Arin et al. [22] show in what way the frameworks of the digital twins can integrate the data on compliance with the requirements from several regulatory sources. However, both approaches assume the presence of the basic level of the well-formulated and explicitly expressed rules, that is, exactly that preliminary condition, with which the inherited systems, based on the SNiP, do not correspond.

2.4. Synthesis and Identified Research Gap

In total, the literature distinctly confirms the global transition to hybrid systems, combining the form-based and result-oriented approaches with the support of automated digital instruments. However, a large part of these researches is based on the contexts, where the regulatory flexibility already exists. The missing element remains the methodology of the transformation of the highly centralized and rigid regulatory systems, similar to those that are characteristic for the post-Soviet region, into the adaptive and digitally ready formats [6, 16].

To the present day, there are no published researches that systemically map the obstacles for the algorithmization of the inherited codes, such as SNiP, and propose a framework model that simultaneously reforms both the content of these codes, from the prescriptive to the result-oriented approach, and their structure, from the text to the machine-readable logic. The present research is aimed at filling this insufficiently studied direction.

3. Materials and Methods

To meet the research aim, a hybrid mixed-methods approach was applied, combining qualitative legal comparison, quantitative spatial modelling, and a practical experiment focused on converting regulatory norms into algorithmic form. The study unfolded in three structured phases, summarised in Figure 1.

3.1. Phase I: Comparative Analysis and the Digital Readiness Matrix

The first stage included a detailed content analysis of the urban planning regulatory documents with the aim of revealing the fundamental structural differences between the rigid prescriptive norms characteristic for the post-Soviet systems, and the more flexible form-based or result-oriented regulatory frameworks applied in the western contexts. For the representation of the post-Soviet model, three official planning documents were selected, currently in force in Astana: SNiP RK 3.01-01As-2007 «Planning and Development of the City of Astana», SNiP RK 3.01-02As-2016 «Norms and Rules of the Design of the Complex Improvement on the Territory of the City of Astana» and SP RK 3.01-101-2013 «Urban Planning. Planning and Development of the Urban and Rural Settlements» [16, 17].

In total, these documents reflect the prescriptive approach to urban planning regulation, which still dominates in the Kazakhstani planning practice. As comparative reference points, two modern regulatory systems were selected, differing by their regulatory logic and by the level of digital realization. The Buffalo Green Code, Unified Development Ordinance, represents the model of a form-shaping code (Form-Based Code), in which the priority is given to the physical form of the urban development, and not to the functional zoning [11].

The Vienna Building Code and the connected OIB-Guidelines were selected in connection with their developed integration into the OpenBIM environments, which provides the possibility of the automated checking of the rules and of the machine-readable procedures of the assessment of the compliance [7].

3.1.1. Substantiation of the Selection of the Cases

Three systems were selected in such a way as to cover the differences in the level of digital readiness, with the simultaneous control of the scale and of the function. All three systems regulate the medium-rise multifunctional development at the municipal level; all three are available in the full text format; together they cover three different regulatory traditions: the post-Soviet prescriptive model, represented by Kazakhstan, the continental result-oriented model, represented by Vienna, and the Anglo-American form-shaping model, represented by Buffalo. Such purposeful variation allows the maximum strengthening of the contrast in the comparative analysis.

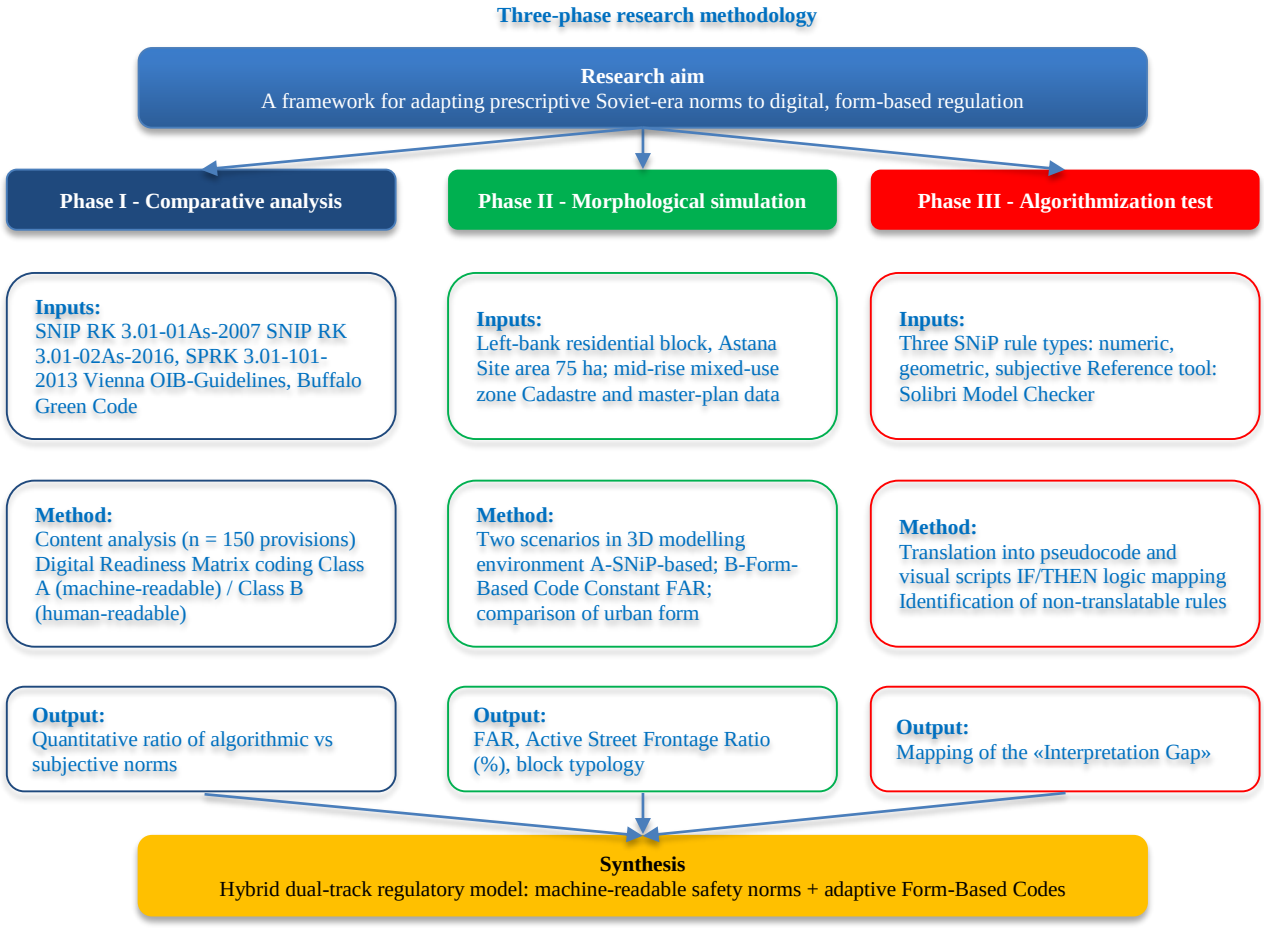

Fig. 1 Three-phase research design linking regulatory text analysis (Phase I), spatial outcomes (Phase II), and algorithmic translation (Phase III) toward a hybrid regulatory framework

Table 1. Criteria for the classification of regulatory requirements under the digital readiness matrix

Class	Criteria	Examples
Class A — Machine-readable	Explicit numerical, geometric, or Boolean (yes/no) parameters. Direct «IF-THEN» translation. Markers: numbers, %, m, «not less than», «not more than», «prohibited».	«Building height must not exceed 24 m.» «Glazing on the ground-floor façade must be at least 60%.»
Class B — Human-dependent	Qualitative adjectives, evaluative statements, legal caveats. Cannot be algorithmized directly. Markers: «as a rule», «with justification», «is permitted», «visual comfort», «harmonious».	«As a general rule, it should be provided that…» «A reduction is permitted with appropriate justification.»

3.1.2. Sampling and Coding

A target sample of 150 regulatory provisions was formed, 50 from each system, with the focus on the zones of the medium-rise multifunctional development.

Each provision was classified with the use of the specially developed Digital Readiness Matrix, which divides the requirements into those compatible with the machine interpretation (Class A) and those dependent on the human judgement (Class B). The criteria and the indicators of the matrix are summarized in Table 1.

All provisions were coded by the authors as a single expert coder, with reliance on the professional experience of the work with the Kazakhstani and the international urban planning norms. The coding scheme was iteratively refined on the pilot subsample of 20 provisions, after which the ambiguous cases were reviewed in several rounds until the achievement of internal consistency. Although the formal statistics of the inter-coder reliability was not calculated, the given procedure allows us to consider the content analysis as an expert-oriented, but systemically documented classification, and not as an arbitrary reading of the text. The

results of the coding are presented in the form of the percentage distribution by the classes for each system; the comparison of the obtained distributions with the use of the chi-square criterion confirms that the difference between Kazakhstan and the two western systems is statistically highly significant ($p < 0.001$).

3.2. Phase II: Case Study and Morphological Scenario Simulation

To explore how different types of urban regulation shape a city's physical form, a design experiment was conducted on a real site in Astana. The method follows a scenario-based modelling approach similar to that of Mortaheb et al. [18].

3.2.1. Study Area

A standard undeveloped residential block on Astana's left bank was selected (Figure 2). The site covers approximately 75 hectares and is designated for mid-rise mixed-use development under the city's master plan. Two regulatory regimes were modelled on the same plot at the same Floor Area Ratio (FAR), so that any difference in the resulting urban form could be attributed to the regulatory regime rather than to development intensity.

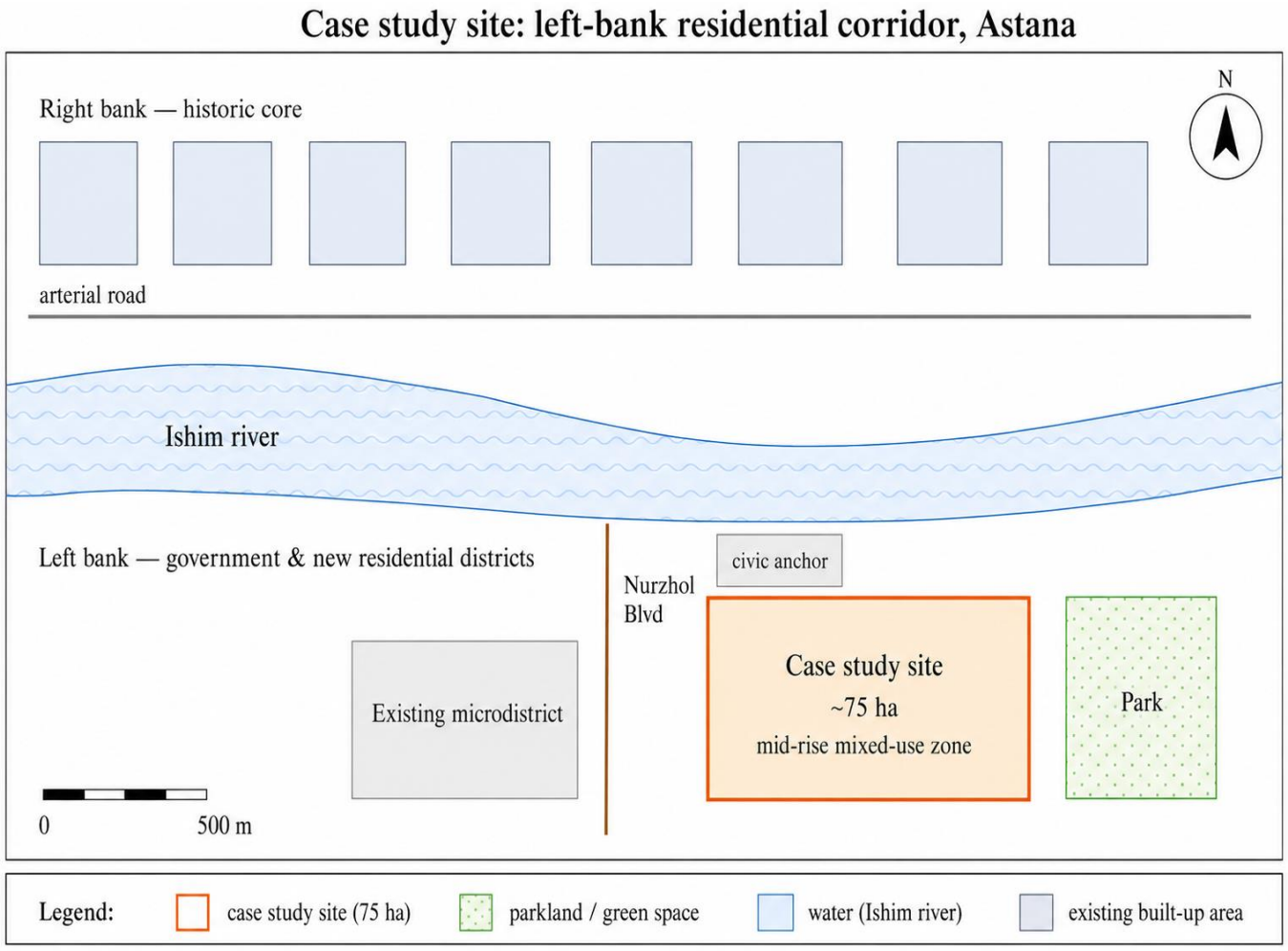

Fig. 2 Location of the 75-hectare left-bank residential corridor in Astana selected for morphological simulation in Phase II. The site is bounded by Nurzhol Boulevard, an arterial road, and an existing parkland buffer

3.2.2. Scenario A, status quo on the basis of SNiP

The first scenario provided for the application of the current Kazakhstani urban planning norms, including SP RK 3.01-101-2013 and SNiP RK 3.01-01As-2007, with their characteristic requirements for the insolation, the fire-prevention gaps and the norms of the provision with the parking places.

3.2.3. Scenario B, Form-Shaping Code

The second scenario provided for the application of a hypothetical form-shaping code, adapted to the conditions of Astana and developed on the basis of the Buffalo Green Code [11]. The given scenario was characterized by the obligatory building lines, the requirements for the transparency of the first floors and the perimeter quarter typology.

Both scenarios were modelled in the 3D CAD environment, after which four morphological indicators were calculated: the coefficient of the use of the territory (Floor Area Ratio, FAR); the share of the active street front (Active Street Frontage Ratio); the share of the ground parking; and also the average distance to the nearest active front. The share of the active street front is defined as the ratio of the total length of the street perimeter, formed by the facade of a building with the active functions of the first floors, including the entrances, the shop windows and the transparent facades, to the total length of the street perimeter, expressed in percent. As a comparative reference point, international guidelines for urban design often consider 60% of the active front as the basic indicator of the pedestrian saturation and of the liveliness of the urban environment [1].

3.3. Phase III: Algorithmization Experiment

At the third stage, a small group of representative provisions of SNiP RK was selected and translated into machine-readable form with the aim of revealing the concrete linguistic and logical obstacles for the automation. Three types of rules were selected: a simple numerical rule (the minimum share of the greenery); a geometrically complex rule (the duration of the insolation); and also a subjective or ambiguous rule, for example, «as a rule, to ensure the visual connection with the river». Each rule was translated both into the pseudocode and into the visual scripts, suitable for the model checking instruments, such as Solibri Model Checker [19]. The pseudocode was constructed by the IF/THEN structure, standardized in the BIM-oriented systems of the rule checking [10].

The given stage allowed to reveal the «Interpretation Gap», that is, the totality of the linguistic and logical problems in the traditional regulatory documents, such as SNiP, which obstruct the fully automatic interpretation. Such gaps, as a rule, require human interpretation and an expert decision. On this basis, a theoretical model of the hybrid validation process was proposed, combining the automated instruments with the expert control. In total, the three stages of the research connect the textual architecture of the urban planning norms, their spatial consequences on the real plot in Astana, and the degree of their algorithmic processability within the framework of the forming BIM-oriented instruments of compliance verification.

3.4. Ethical Considerations

The research did not include the participation of the people, the conducting of the interviews or the processing of the personal data; consequently, the formal approval of the institutional ethical committee was not required. All analyzed regulatory documents are the official and publicly available legal texts, including SNiP RK, SP RK, OIB-Guidelines and the Buffalo Green Code, and they are fully indicated in the list of references. The cadastral information and the data of the general plan, used for the morphological modelling of the plot in Astana, were obtained from the publicly available municipal sources and do not contain personal or commercially confidential data. At the same time, the authors recognize the wider ethical aspects connected with the digital instruments, considered in the given article. The systems of the Automated Code Compliance Checking can introduce algorithmic opacity into the processes of the taking of the decisions on the permit documentation. Therefore, their integration into the system of the state administration raises the questions of transparency, accountability and equal access. The hybrid model, proposed in Section 5.3, directly preserves the expert verification by the human for the cases that relate to the «Interpretation Gap», including as a response to the indicated concerns.

4. Results

In the given section, the key results obtained during the realization of the three-stage research methodology are presented. The results are structured in correspondence with the consecutive logic of the analysis: from the comparative quantitative assessment of the normative-regulatory base to the morphological modelling and to the algorithmization experiment.

4.1. Results of the Comparative Analysis and the Digital Readiness Matrix

The first stage of the research was aimed at the quantitative assessment of the structural differences between the prescriptive post-Soviet regulatory model and the modern western approaches to urban planning regulation. The content analysis of the representative sample of the regulatory requirements (n = 150), conducted with the use of the Digital Readiness Matrix, revealed a fundamental divergence in the degree of formalization of the regulatory text. As shown in Figure 3, the structure of the Kazakhstani regulatory documents (SP RK and SNiP RK) significantly differs from the structure of the norms of Vienna and Buffalo.

Approximately 70% of the requirements in the Kazakhstani sample relate to the subjective or dependent on human interpretation category. These provisions rely on the qualitative criteria and the legal reservations, such as «as a rule», «when substantiated» or «visual comfort», which, from the technical point of view, obstructs their direct algorithmization. In contrast with this, the analyzed sections of the norms of Vienna and Buffalo consist respectively of 88% and 87% of the machine-readable requirements, based on the parameters, with the average value of 87.4%. These requirements are built on the explicitly defined geometric constraints, such as the zones of the obligatory placement of the development, measurable percentage indicators or Boolean conditions. This confirms the hypothesis that the linguistic and structural configuration of the post-Soviet norms is the main barrier for the introduction of the automated procedures of the compliance verification in the BIM-environments [3, 10, 20].

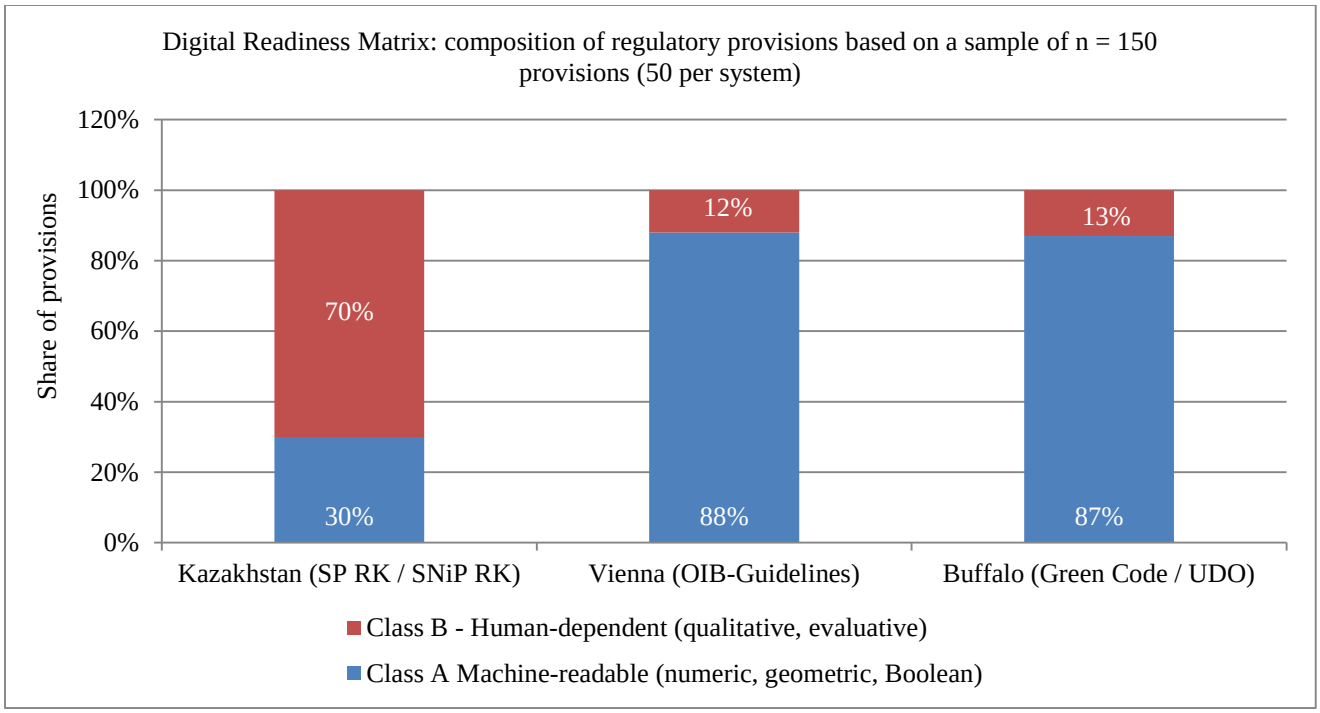

Fig. 3 Stacked composition of regulatory provisions classified under the digital readiness matrix

Table 2. Benchmark comparison of Digital Readiness Matrix outcomes across the three systems

System	Class A	Class B
Kazakhstan (SP RK / SNiP RK)	30%	70%
Vienna (OIB-Guidelines)	88%	12%
Buffalo (Green Code / UDO)	87%	13%

4.2. Morphological Simulation Results: Astana Case Study

In the second phase, 3D modelling of the Astana test site revealed how regulatory frameworks visibly shape the city's form. The simulation showed that the regulatory system is not merely a technical tool: it directly defines how urban spaces take shape (Figure 4).

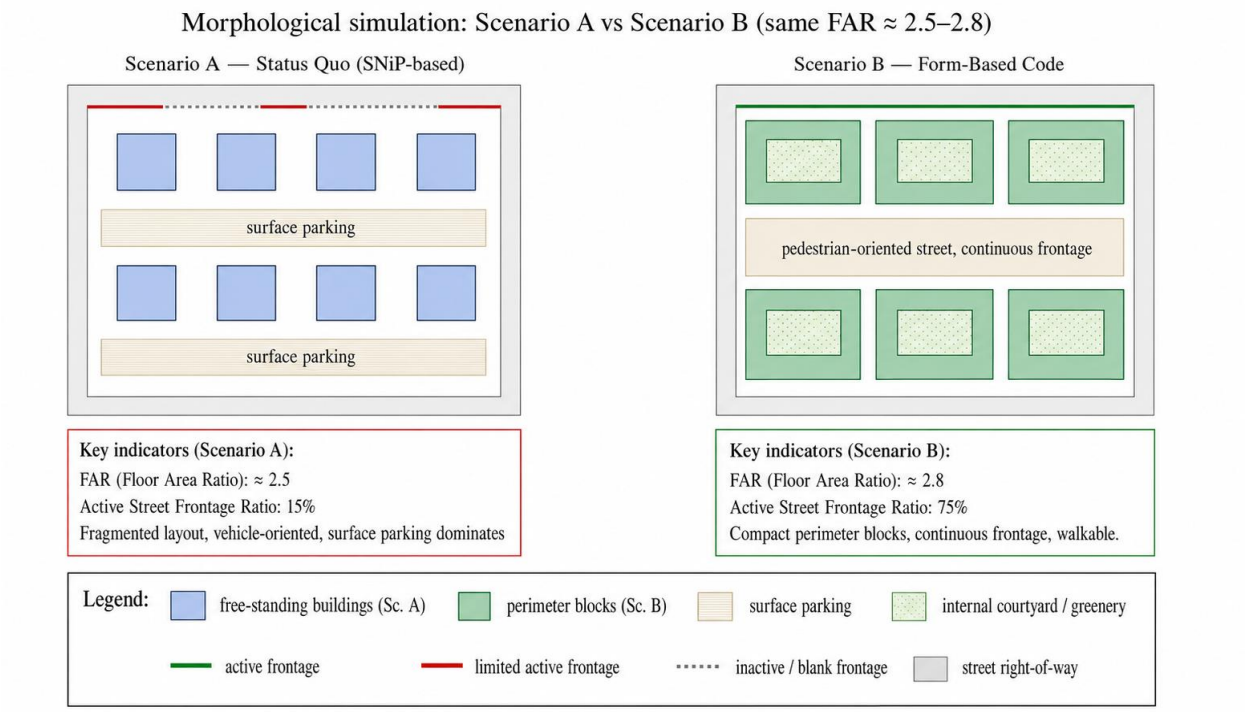

Fig. 4 Comparative morphological simulation of the same 75-hectare left-bank site under two regulatory regimes

4.2.1. Scenario A, Status Quo (SNiP-based)

This scenario follows current Kazakhstani planning norms. The strict rules on sunlight access and fire-safety setbacks lead to widely spaced buildings, leftover open areas, and a heavy reliance on surface parking. The result is a fragmented layout with little definition of public space. The Active Street Frontage Ratio in this scenario was only 15%, indicating poor walkability and low street-level activity.

4.2.2. Scenario B, Form-Based Code

The FBC scenario applies tools such as mandatory build-to lines and ground-floor transparency requirements. It produces a compact perimeter-block layout that clearly distinguishes public streets from private spaces. Although both scenarios maintained a similar building density (FAR between 2.5 and 2.8), Scenario B achieved a significant improvement in pedestrian-oriented development. The Active Street Frontage Ratio increased to 75%. As a benchmark, international urban-design guidelines often identify 60% active frontage as a threshold for pedestrian vibrancy [1]; this threshold is exceeded only in Scenario B.

Table 3. Comparative morphological indicators for the two simulation scenarios

Indicator	Scenario A — SNiP	Scenario B — FBC
Floor Area Ratio (FAR)	≈ 2.5	≈ 2.8
Active Street Frontage Ratio	15%	75%
Surface parking share of plot	≈ 22%	≈ 6%
Block typology	free-standing towers	perimeter blocks

4.3. Algorithmisation Results and the Interpretation Gap

In the third stage, the selected SNiP provisions were translated into machine-readable pseudocode. This practical experiment helped to identify why many of these norms resist automation, a challenge that is described as the «Interpretation Gap». The tested regulations fell into three categories (Figure 5).

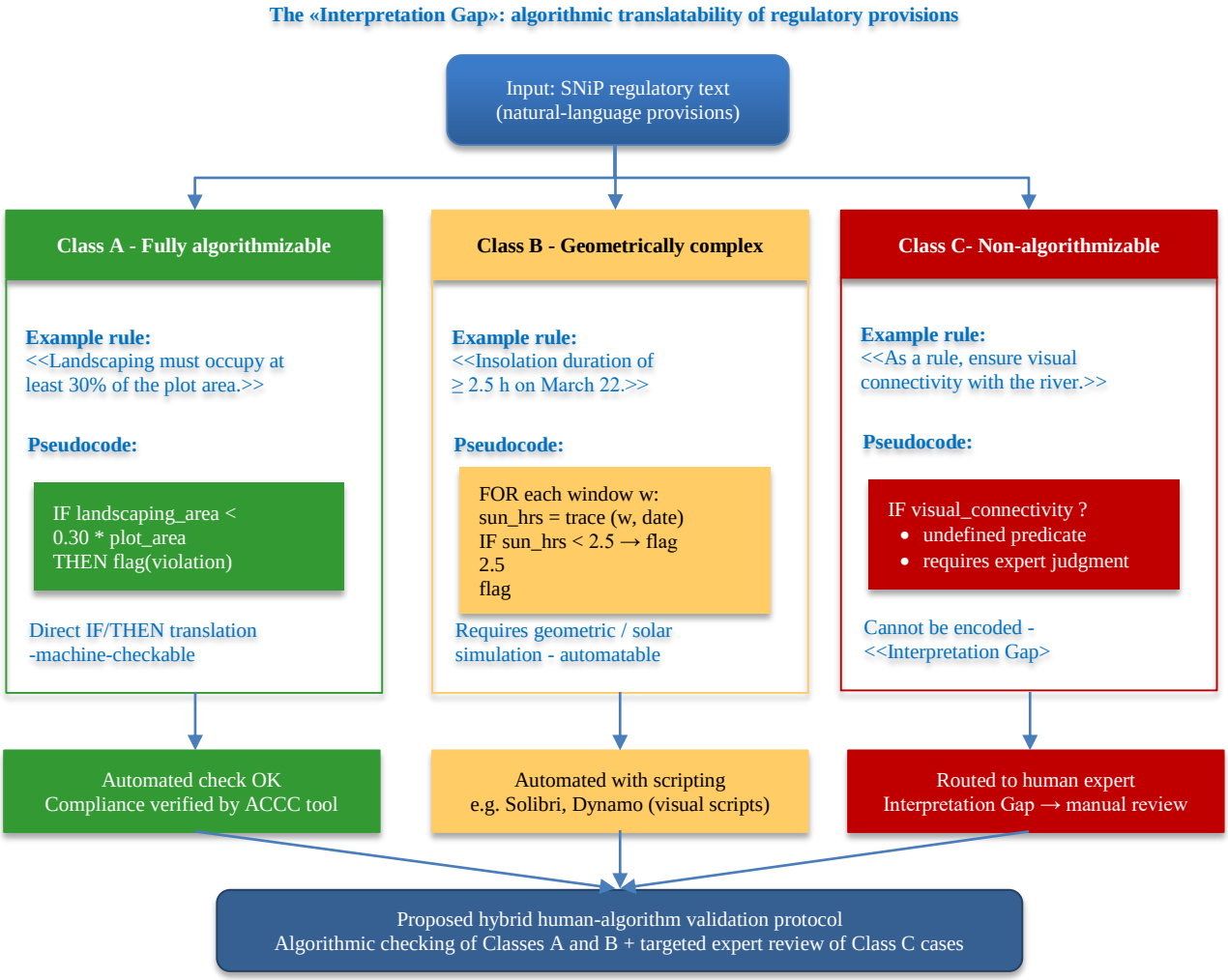

Fig. 5 Three-tier classification of regulatory provisions by algorithmic translatability

4.3.1. Fully Algorithmizable Provisions

Straightforward numerical rules, such as required landscaping percentages, translated cleanly into simple IF/THEN logic and can be reliably handled by compliance-checking software.

4.3.2. Geometrically Complex but Automatable Provisions

Rules involving spatial relationships, such as sunlight access or emergency-vehicle access routes, required more advanced scripts but could still be automated with effort, typically through a combination of geometric queries on the BIM model and external solar simulation.

4.3.3. Non-Algorithmizable Provisions (Interpretation Gap)

Subjective rules, like those flagged in Section 4.1 (e.g. «visual comfort», «as a rule»), could not be translated into code. As shown in Figure 5, attempts to encode them led to dead ends; such cases require human interpretation and must be redirected to expert review. The experiment confirms that without structural changes to the way rules are written, digital tools will inevitably hit a wall, not because of technological limits, but because the language itself blocks automation [3, 4, 10].

5. Discussion

The significance of these results goes far beyond the limits of the city of Astana. The obtained data indicate a deep mismatch between the post-Soviet system of urban planning and the requirements of modern planning, especially in the part of the quality of the urban environment and digitalization. In addition, they allow to more precisely reveal the basic problems with which the cities of the post-socialist region are faced in the conditions of rapid urbanization.

5.1. The Density Paradox and Regulatory Morphology

One of the most significant conclusions of the present research is that the urban form is determined not so much by the market demand or by the architectural design, as by the very structure of the regulatory system. This was clearly demonstrated by the results of the modelling: despite the comparable values of the coefficient of the use of the territory (Floor Area Ratio, FAR ≈ 2.5–2.8), the results of the application of the two regulatory models significantly differed. Under the current Kazakhstani SNiP norms (Scenario A), a fragmented, automobile-oriented planning structure is formed, in which the share of the active street front constitutes only 15%. On the contrary, the scenario of the form-shaping code (Scenario B) formed a compact, pedestrian-accessible perimeter quarter structure with 75% of the active front without the loss of density. The given result is in agreement with the previous researches, in particular with the work of Mortaheb et al. [18], where it is shown that the form-shaping regulation increases the efficiency of the land use, decreases the dependence on the automobiles and improves the quality of the public space. Consequently, the key problem consists not in what density Astana is capable to withstand, but in in what way this density is organized. This is a direct consequence of the outdated regulatory logic. The given regularity reflects what Stanilov [6] defines as the legacy of the post-socialist spatial regimes, namely the discrepancy between the potential of the density and the form of the urban environment suitable for life, rooted in the inherited technocratic standards. Alexander [16] comes to a similar conclusion on the example of Almaty, noting that the inherited rationality of the Soviet planning continues to structure the post-Soviet urban results.

5.2. The Interpretation Gap as a Barrier to Digitalization

Approximately 70% of the key planning rules of SNiP rely on subjective or indefinite language, which sharply contrasts with the average indicator of 87.4% of the machine-readable rules, revealed in the regulatory systems of Vienna and Buffalo. This result shows that the real obstacle consists not in the technology, but in the legal and linguistic framework. The stable barrier, revealed in the given research, is designated as the «Interpretation Gap». Without the fundamental structural reform, the digital instruments will inevitably be faced with this semantic block. The experience of other contexts, for example, of Estonia, shows that the main bottleneck of the digital transition often is the legal ambiguity, and not the technological limitation [8]. If Kazakhstan does not solve the problem of the linguistic structure of its norms, it risks only to digitalize the outdated practices, thereby consolidating the non-transparency and the dependence on manual control. This strengthens the conclusion of Eastman et al. [3], according to which the semantic clarity of the regulatory language is not simply a useful condition, but a necessary prerequisite of the successful automated verification of compliance. The more recent researches, dedicated to the knowledge graphs [21] and to the digital twins [22], confirms that even the complicated ways of the representation of the data about the buildings are not capable to compensate the unresolved ambiguity of the basic legal text.

5.3. Policy Implications: A Hybrid Transition Model

The current trajectory of the insignificant updating of the inherited norms has reached its limit. At the same time, the instantaneous transition to the imported western codes is also not practically realizable. A more effective direction of the further development is the hybrid model, which combines the habitual regulatory structures with the digitally ready instruments. In the spheres critically important for the safety, such as the structural reliability and the fire-prevention protection, the prescriptive logic of SNiP should be preserved, but at the same time restructured into machine-readable formats with the reliance on the successful experience of the digitalization of the Austrian OIB-Guidelines as a methodological reference point [20]. At the same time, the outdated urban planning provisions must be replaced by the adaptive mechanisms, first of all, the Form-Based Codes and the Performance-Based Codes (form-shaping codes and codes based on the efficiency indicators) [1, 4]. The adaptation of

these instruments to the local conditions and their embedding into the digital ecosystems of the planning allow this two-loop strategy to simultaneously preserve the continuity and to ensure the innovative development. Such a hybrid approach corresponds to what the researchers of public policy describe as the «two-speed reform», under which the inherited systems develop gradually, in parallel with the introduction of the digital modules of the new generation [23].

5.4. Comparison with State-of-the-Art Approaches

The obtained results are reasonable to consider in comparison with the main modern approaches to Automated Code Compliance Checking. In comparison with the rule classification scheme, proposed by Solihin and Eastman [10], the Digital Readiness Matrix presented in the given research is more narrow by the coverage, since it focuses on the dichotomy between the machine-readable provisions and the provisions dependent on the human interpretation. At the same time, it possesses a higher linguistic sensitivity, since it captures the specific markers of the post-Soviet legal style, such as «as a rule» and «when substantiated», which were not provided for in the earlier classifications. In comparison with the approaches based on the knowledge graphs [21], the matrix functions at the preceding stage it determines which provisions in principle can be formalized before the construction of any graph or ontology. In comparison with the frameworks of the digital twins [22], it does not replace, but complements them, since it provides the diagnostic stage, which at present is absent in the post-Soviet trajectory of the introduction. The empirical contrast (approximately 70% against 87.4% of the machine-readable provisions), to the best of the authors' knowledge, is the first similar comparative reference point for the post-Soviet regulatory system and may be useful for the subsequent comparison with the neighbouring jurisdictions of Central Asia and the South Caucasus.

5.5. Limitations

The given research has several limitations. Firstly, the morphological simulation was based on one type of zoning, namely on the high-density medium-rise residential development, and on a concrete city, possessing its own climatic, historical and political conditions. Therefore, the generalization of the morphological indicators to other cities of Kazakhstan and to other post-Soviet contexts requires further empirical researches. Secondly, the content analysis used a target sample of the regulatory provisions (n = 150), and not the whole regulatory corpus. Although the samples of 50 provisions for each system are sufficient for revealing of the large structural differences, the full corpus analysis would allow to obtain a more precise picture, especially with regard to the borderline categories. Thirdly, the coding was performed by the authors as a single expert coder. Despite the fact that the pilot stage and the iterative refinement were applied for the provision of the internal consistency, the formal indicator of the inter-coder reliability could not be presented. Fourthly, the algorithmization experiment at Stage III checked three representative types of rules, and not the full catalogue of the regulatory provisions, and was performed with the use of the pseudocode, and not of a fully integrated BIM platform.

5.6. Future Research Directions

Taking into account the indicated limitations, four directions of further researches can be designated. Firstly, the Digital Readiness Matrix may be applied to the whole corpus of SP RK and SNiP RK, with the subsequent re-coding by independent experts for the obtaining of a statistically stable national reference point. Secondly, the morphological simulation may be extended to additional categories of the zoning, including the low-rise residential, commercial and industrial development, and also to other post-Soviet capitals, for example, Tashkent, Bishkek and Minsk, with the aim of the verification of the inter-context generalizability of the obtained results. Thirdly, the pilot projects on the introduction of the proposed hybrid validation protocol into the real BIM-oriented process of the issuance of permits are seen as valuable, preferably in the format of a partnership between the municipal organs and the software providers. Fourthly, the longitudinal researches of the institutional, managerial and social consequences of the automated verification of compliance, including the questions of the algorithmic transparency and of the citizen participation, would allow to ensure that the digital transition serves the wider public interests, and not the narrow technocratic goals.

6. Conclusion

The present research was aimed at the consideration of the fundamental contradiction between the inherited post-Soviet regulatory frameworks and the modern requirements for the formation of a comfortable urban environment, and also for the digitalized processes in the construction. With the use of a mixed methodological approach, including the comparative content analysis, the morphological modelling and the testing of the algorithmization, three main conclusions were obtained in the research, each of which directly answers one of the research questions, formulated in Section 1.2.

In response to RQ1 (structural incompatibility with digitalization), it is established that the current norms of Kazakhstan (SNiP RK and SP RK) are fundamentally not in agreement with the digital work processes. Approximately 70% of the SNiP rules in the analyzed sample rely on subjective interpretation, whereas on average, 87.4% of the rules of Vienna and Buffalo are defined through clear, machine-readable parameters. The given structural gap blocks the automation.

In response to RQ2 (the regulation–form link), the simulation on the plot in Astana showed that the urban form does not simply experience the influence of the regulation, but to a significant degree is determined by it. Even under the

same density of the development (FAR ≈ 2.5–2.8), the SNiP norms form disconnected, automobile-oriented spaces, where the share of the active street front constitutes only 15%. On the contrary, the principles of the Form-Based Code ensure the formation of the pedestrian-accessible compact quarters with the share of the active front up to 75%, which significantly better supports public life.

In response to RQ3 (the Interpretation Gap as a digital barrier), it is established that the attempts of the digitalization of the existing norms are faced with failure in the presence of the indefinite legal language, for example, the formulations of the type «as a rule». Such formulations violate the algorithmic logic and demonstrate that without the rewriting of the legal language itself, the automation will not be capable to be successful.

From the methodological point of view, in the research, the Digital Readiness Matrix was developed and applied, an original classification instrument for the assessment of the algorithmic compatibility of the urban planning norms. It offers a reproducible framework for the assessment of the regulatory systems in the context of the digital transformation, especially in the transitional post-socialist conditions.

On this empirical basis, the research proposes a two-loop reform strategy. The first loop is connected with the codification of the safety norms: the translation of the critically important requirements of the health and safety protection (such as the access of the fire equipment and the structural stability) into the machine-readable logic with the use of approaches analogous to the Austrian OIB-Guidelines. The second loop is connected with the adaptive urban planning instruments: the replacement of the outdated urban planning norms by the context-sensitive Form-Based Codes, applied at the level of the detailed planning for the improvement of the morphological structure and for the increase of the liveliness of the street space. Only a deep structural reform, and not a superficial cosmetic digitalization, is capable to close the «Interpretation Gap» and to ensure real progress. The given approach offers a scalable model, based on the politics, the technologies and the institutional changes, for Kazakhstan and other post-Soviet countries, striving to overcome the gap between the inherited principles of urban planning and the modern requirements of the digital regulation.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Funding Statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgments

The authors gratefully acknowledge the colleagues at the Republican Centre of State Urban Planning and Cadastre RSE (Astana) for the fruitful discussions on the regulatory framework, and the staff of the master-planning departments who provided access to the cadastral and master-plan data used in the morphological simulation.

References

[1] Daniel G. Parolek, Karen Parolek, and Paul C. Crawford, *Form-based Codes A Guide for Planners, Urban Designers, Municipalities, and Developers*, John Wiley & Sons, pp. 1-332, 2008. [Google Scholar] [Publisher Link]

[2] Emily Talen, "Zoning for and Against Sprawl: The Case for Form-Based Codes," *Journal of Urban Design*, vol. 18, no. 2, pp. 175-200, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[3] C. Eastman et al., "Automatic Rule-Based Checking of Building Designs," *Automation in Construction*, vol. 18, no. 8, pp. 1011-1033, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[4] Nawari O. Nawari, *Building Information Modeling Automated Code Checking and Compliance Processes*, Boca Raton, CRC Press, pp. 1-176, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[5] R. Rijanta et al., "Frontier Urbanisation in East Kalimantan: Displacement, Livelihood Shifts, and Contested Development in Indonesia's New Capital," *International Journal of Sustainable Development and Planning*, vol. 20, no. 8, pp. 3541-3551, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[6] Kiril Stanilov, *The Post-Socialist City: Urban Form and Space Transformations in Central and Eastern Europe after Socialism*, Springer Dordrecht, 1st ed., pp. 1-496, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[7] Harald Urban, Simon Fischer, and Christian Schranz, "Adapting to an Open BIM Building Permit Process: A Case Study Using the Example of the City of Vienna," *Buildings*, vol. 14, no. 4, pp. 1-24, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[8] Kaleem Ullah, Irene Lill, and Emlyn Witt, *An Overview of BIM Adoption in the Construction Industry: Benefits and Barriers*, pp. 297-303, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[9] Fernanda Schmitd Villaschi, José Pedro Carvalho, and Luís Bragança, "BIM-Based Method for the Verification of Building Code Compliance," *Applied System Innovation*, vol. 5, no. 4, pp. 1-17, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[10] W. Solihin, and C. Eastman, "Classification of Rules for Automated BIM Rule Checking Development," *Automation in Construction*, vol. 53, pp. 69-82, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[11] Duygu Gökce, "Enhancing Sense of Place Through Form-Based Design Codes: Lived Experience in Elmwood Village under Buffalo's Green Code," *Urban Science*, vol. 9, no. 7, pp. 1-26, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[12] Dalit Shach-Pinsly, and Isaac Guedi Capeluto, "From Form-Based to Performance-Based Codes," *Sustainability*, vol. 12, no. 14, pp. 1-20, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] Jae Teuk Chin, "Coding for Predictive Built Environments: Building and Street Typology Choices in Form-based Codes," *Journal of Asian Architecture and Building Engineering*, vol. 23, no. 1, pp. 355-371, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[14] Ikrar Adinata Arin, Dina Fitria Murad, and Harco Leslie Hendric Spits Warnars, "Digital Twin Integration in Field Service Management: A Hybrid Systematic Literature Review and Bibliometric Analysis (2017-2024)," *International Journal of Sustainable Development and Planning*, vol. 20, no. 8, pp. 3155-3169, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[15] Helen Eriksson et al., "Requirements, Development, and Evaluation of a National Building Standard—A Swedish Case Study," *ISPRS International Journal of Geo-Information*, vol. 9, no. 2, pp. 1-27, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[16] Catherine Alexander, "Soviet and Post-Soviet Planning in Almaty, Kazakhstan," *Critique of Anthropology*, vol. 27, no. 2, pp. 165-181, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[17] Assel Shaldykova et al., "Comparative Analysis of Kazakhstani and European Approaches for the Design of Shallow Foundations," *Applied Sciences*, vol. 10, no. 8, pp. 1-11, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[18] Reza Mortaheb et al., "Form-Based Code Revisited: Leveraging Geographic Information Systems (GIS) and Spatial Optimization to Chart Commuting Efficiency Landscapes under Alternative City Planning Frameworks," *Land*, vol. 13, no. 8, pp. 1-31, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[19] Solibri Model Checker v9.1.29 Release Notes, Solibri, 2018. [Online]. Available: https://www.solibri.com/articles/solibri-model-checker-v9-1-29-release-notes

[20] Sihao Li, Ziyang Jiang, and Zhao Xu, "BIM-Based Model Checking: A Scientometric Analysis and Critical Review," *Applied Sciences*, vol. 15, no. 1, pp. 1-2024. [CrossRef] [Google Scholar] [Publisher Link]

[21] Junlong Peng, and Xiangjun Liu, "Automated Code Compliance Checking Research based on BIM and Knowledge Graph," *Scientific Reports*, vol. 13, pp. 1-12, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[22] Miles Glendinning, *Mass Housing and Extensive Urbanism in the Baltic Countries and Central/Eastern Europe: A Comparative Overview*, Housing Estates in the Baltic Countries the Legacy of Central Planning in Estonia, Latvia and Lithuania, Springer, Cham, pp. 117-136, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[23] Beata Kviatek, *Explaining Legal Transplants: Transplantation of EU Law into Central Eastern Europe*, Wolf Legal Publishers, pp. 1-492, 2015. [Google Scholar] [Publisher Link]